Executive Summary

SHC Study

Robert O. Miller, Colorado State University

The Saturated Hydraulic Conductivity project was initiated in 1999 to evaluate documented variability problems in the saturated hydraulic conductivity (K_{sat}) method and develop a revised method for use by the rootzone testing lab industry. Phase I of this project was to complete a laboratory site assessments of each of the testing laboratories to evaluate the implementation of ASTM method 1815-97 used to determine K_{sat}. Results indicate the current method insufficiently describes cylinder loading (step1) and column saturation (step 2) of the method which contributes to inter-lab method variability in K_{sat}, capillary and non-capillary moisture values. As a result of the Site Assessments, phase II of the study was initiated to address the impact of antecedent (initial sample moisture upon laboratory reception) on K_{sat} values. Results from four testing labs indicate with increases in antecedent moisture from 1.0% to 14%, K_{sat} values falls substantially dependent upon lab and root zone material source. Antecedent moisture variability only effects K_{sat} values and has no bearing on capillary, non-capillary or bulk density parameters. Preliminary results suggest that antecedent moisture contents between 6 and 10% have little influence on K_{sat} values Phase III of the study was to develop standard reference K_{sat} columns for assessing percolation tables used by the testing labs. Five standard reference columns have been constructed and tests indicate that these columns provide very consistent K_{sat} values. Based on these results proposed revisions to ASTM 1815-97 will need to: (1) specify a antecedent moisture of root zone mixes; (2) develop standardized cylinder loading techniques; and (3) all percolation table designs used in the testing labs will need to be evaluated using standard reference K_{sat} columns.

SHC Study
Project Progress Report October 16, 2000

Robert O. Miller, Colorado State University, USGA-PT Program Coordinator

The SHC project was initiated in 1999 to evaluate variability problems in the K_{sat} method and develop a revised method for use by the testing lab industry. This progress report is presented in three sections: Laboratory Site Assessments; Antecedent Moisture Study; and Reference K_{sat} Columns.

Laboratory Site Assessments

Beginning in July 1999 and ending in May 2000, thirteen root zone testing labs (Table 1) were visited to assess the implementation of ASTM standard test method F1815-97, saturated hydraulic conductivity (K_{sat}), water retention, porosity, particle density, and bulk density. Laboratory site assessment consisted of: documentation of instrumentation, video documentation of K_{sat} method implementation; review of USGA-PT proficiency data, collection of water samples and review of laboratory QC procedures.

Table 1. List of labs participating in laboratory site assessments.

Laboratory	**Location**	**Date**
Sports Turf Research Institute (STRI)	Bingley, England, UK	July 1999
European Turfgrass Laboratory * (ETL)	Stirling, Scotland, UK	July 1999
Hepworth Minerals	Stoke on Trent, England, UK	August 1999
Colorado Analytical	Brighton, CO, USA	August 1999
Brookside Laboratories *	New Knoxville, OH, USA	September 1999
Turf Diagnostics and Design *	Olathe, KS, USA	October 1999
Thomas Turf *	College Station, TX, USA	November 1999
Hummel & Company *	Trumansburg, NY, USA	December 1999
Tifton Soil Testing *	Tifton, GA, USA	January 2000
Turf Science Inc.	Phoenix, AZ, USA	February 2000
ISTRC *	Olathe, KS, USA	April 2000
Rugers University	New Burnswick, NJ, USA	May 2000
Dakota Peat	Grand Forks, ND	May 2000

* A2LA Accredited laboratory. Note only one A2LA lab refused a site visit.

Results

The K_{sat} can be divided into eight steps: (*1*) loading of the cylinder with root zone mix; (*2*) saturation of the cylinder; (*3*) application of 30 cm tension; (*4*) compaction of sample; (*5*) resaturation of the sample (*6*) percolation test; (*7*) resaturation of the cylinder; and (*8*) 2^{nd} application of 30 cm tension. Cylinders utilized by the testing laboratories ranged from 50 to 84 mm in diameter and from 65 to 105 mm in height, and were fabricated from, brass, steel, plastic and copper. Cylinder base coverings ranged from cheese cloth, nylon mesh to metal screen. Tension tables were primarily based on blotter paper with attached column, but sand table construction was noted in three laboratories. Compactors were for the most part uniform between laboratories and hammer weight variation was proportional with cylinder diameters, although there was variation in compactor base support. Percolation table design was highly laboratory dependent and measurement of cylinder water flux was inconsistent with method ASTM 1815-97.

Steps *1, 2, 5* and *7* involve a high degree of laboratory technique for implementation. Based on laboratory site visits, ASTM F 1815-97 insufficiently describes cylinder loading and column saturation as implemented in the laboratories. Based on video documentation column loading varies greatly among the labs, with some labs simply filling the columns with root zone mix to one lab utilizing a pestle to compact the mix in layers within the cylinder (Figure 1a - 1c). Columns which are highly compacted lead to high moisture content for step *3* and higher bulk density. Variation in loading technique was sufficient to suggest that this is a major point of variability in K_{sat}, capillary porosity, non capillary porosity and bulk density noted in the USGA-PT quarterly proficiency data noted over the past three years.

Variation in laboratory technique in column saturation (Steps *2, 5, 7*) was noted, however it was lesser than that noted for cylinder loading. In five labs it was documented that columns were not fully saturated and or the saturation time was longer or shorter than that stated in ASTM 1815-97. Insufficiently saturated columns would lead to a lower water contents on the tension table prior to compaction (step *3*) and lower capillary water contents after step *7*.

Results of laboratory water quality are being compiled and will be available in January 2001. It was noted water temperature was highly variable between labs and varied seasonally, with a range of 2 - 35 °C noted.

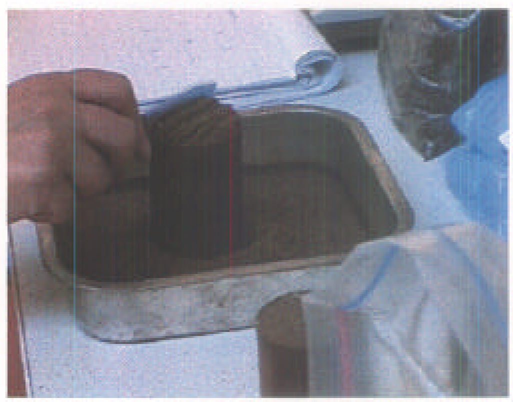
Inconsistency was noted in the determination of column height (utilized in the calculation of bulk density). This is likely associated with either the measuring device utilized or with the technique employed in measuring root zone height in the cylinder.

Thanks needs to be given to the testing labs for their cooperation, comments and suggestions for making the site assessment study highly effective.

Figure 1. Cylinder loading techniques employed by three labs.

Scoop Filled (1a)

Filled and leveled (1c)



Packed with a pestle (1c)

Antecedent Moisture Study

As a result of the Laboratory visits it was noted by ETL and STRI labs that the initial moisture content , or antecedent moisture has an impact on the K_{sat} value of the root zone mix. Over the last five months four green zone mixes were collected from four regions of the USA to evaluate the effect of antecedent moisture.

Four root zone mixes were equilibrated to seven moisture contents ranging from 0.5 to 14% moisture. These materials were submitted to six root zone testing labs (Table 2) across North America and Scotland for evaluation of antecedent moisture (moisture upon reception at the lab) on K_{sat} (SHC), capillary, noncapillary, and bulk density. Labs provided results in triplicate or duplicate, dependent on the testing laboratory. Materials collected were from root zone stock piles from Plaisted Inc. Elk River, MN, Hall Irwin's Brighton, CO operation, TXI's Austin, TX operation and Golf Agronomics Sarasota, FL operation. These were selected based on diversity across the United States.

Table 2. List of labs participating in antecedent moisture study.

Laboratory	**Location**
ETL *	Stirling Scotland
Turf Diagnostics and Design *	Olathe, KS, USA
ISTRC *	Olathe, KS, USA
Hummel & Company *	Trumansburg, NY, USA
Brookside Laboratories *	New Knoxville, OH, USA
Dakota Peat	Grand Forks, ND, USA

* A2LA Accredited lab.

Results

The impact of antecedent moisture is presented in Table 3 (page 5), which lists the mean values for K_{sat}, capillary moisture, non capillary moisture and bulk density for each laboratory. For lab A (note K_{sat} values are in mm/hr) show a substantial decline in K_{sat} with increasing antecedent moisture from 1.7 to 14.9%. Cap and non-cap porosity is relatively unchanged for moisture values above 2.9%. Similar declines in K_{sat} and consistency in cap values were noted for lab B using the same Hall Irwin green mix. For the TXI material lab

Table 3. Impact of initial mositure on Ksat, Capillary Mositure, Non Capillary Moisture and Bulk Density.

Laboratory: A
Green Mix Sand: Hall Irwin, Brighton, CO

Initial Moisture	K_{sat}	Capillary Moisture	Non Capillary	Bulk Density
%	mm/hr	%	%	g/cm3
1.7	147	21.9	15.5	1.66
2.9	127	18.8	19.7	1.63
5.2	63.7	18.7	20.5	1.61
7.0	57.3	18.9	20.7	1.60
9.3	42.9	18.9	20.7	1.60
11.1	30.7	18.8	21.6	1.58
14.9	30.9	19.0	21.8	1.57

Laboratory: B
Green Mix Sand: Hall Irwin, Brighton, CO

Initial Moisture	K_{sat}	Capillary Moisture	Non Capillary	Bulk Density
%	in/hr	%	%	g/cm3
-	-	-	-	-
2.5	11.9	15.1	27.3	1.53
4.7	6.8	15.7	27.8	1.49
6.7	6.0	15.6	28.0	1.50
8.0	6.9	15.8	28.6	1.47
9.8	6.4	15.9	27.4	1.49
12.2	6.7	16.1	27.7	1.49

Laboratory: C
Green Mix Sand: TXI, Austin, TX

Initial Moisture	K_{sat}	Capillary Moisture	Non Capillary	Bulk Density
%	in/hr	%	%	g/cm3
1.4	15.1	10.8	27.1	1.67
2.6	12.4	10.5	27.6	1.65
4.4	26.5	10.7	27.7	1.64
6.2	20.0	10.5	28.2	1.64
7.9	14.4	10.8	28.2	1.64
10.8	12.6	11.4	29.2	1.64
13.9	8.4	10.4	26.8	1.65

Laboratory: D
Green Mix Sand: TXI, Austin, TX

Initial Moisture	K_{sat}	Capillary Moisture	Non Capillary	Bulk Density
%	in/hr	%	%	g/cm3
1.7	20.0	13.2	27.3	1.57
3.1	19.6	14.0	25.8	1.59
4.3	14.8	14.4	24.8	1.61
6.2	13.5	14.0	26.1	1.58
8.0	13.0	14.5	26.3	1.57
10.0	13.7	14.2	25.4	1.57
11.7	12.7	14.1	26.5	1.57

Laboratory: E
Green Mix Sand: Golf Agronomics, Sarasota, FL

Initial Moisture	K_{sat}	Capillary Moisture	Non Capillary	Bulk Density
%	in/hr	%	%	g/cm3
0.6	15.7	16.5	20.9	1.64
1.0	17.6	16.3	20.3	1.67
5.3	22.6	16.7	21.3	1.64
7.5	21.2	16.9	21.2	1.64
10.0	20.4	17.7	20.9	1.63
14.3	17.9	18.1	19.9	1.64

Laboratory: F
Green Mix Sand: TXI, Austin, TX

Initial Moisture	K_{sat}	Capillary Moisture	Non Capillary	Bulk Density
%	in/hr	%	%	g/cm3
2.7	15.7	13.5	24.6	1.62
9.7	12.1	14.8	24.0	1.61
11.3	11.7	14.4	24.7	1.62
13.9	10.5	14.7	24.9	1.60
16.1	9.3	15.4	25.1	1.58
-	-	-	-	-

* 1.5 Kg of material was equilibrated for 48 hours at specified moisture content.

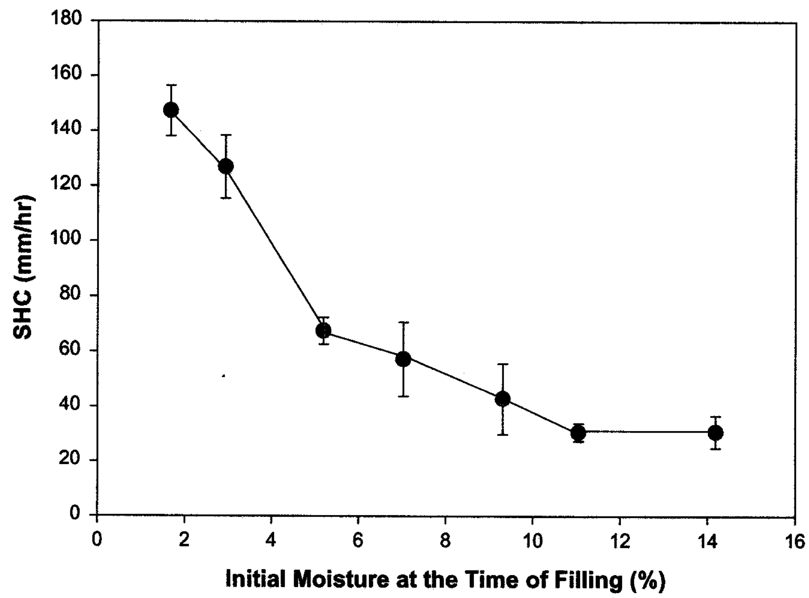


Figure 2. Relationship of initial green mix moisture (at column loading) on final SHC, Lab A. Sample provided by, Hall Irwin Sand Company, Brighton, Colorado.

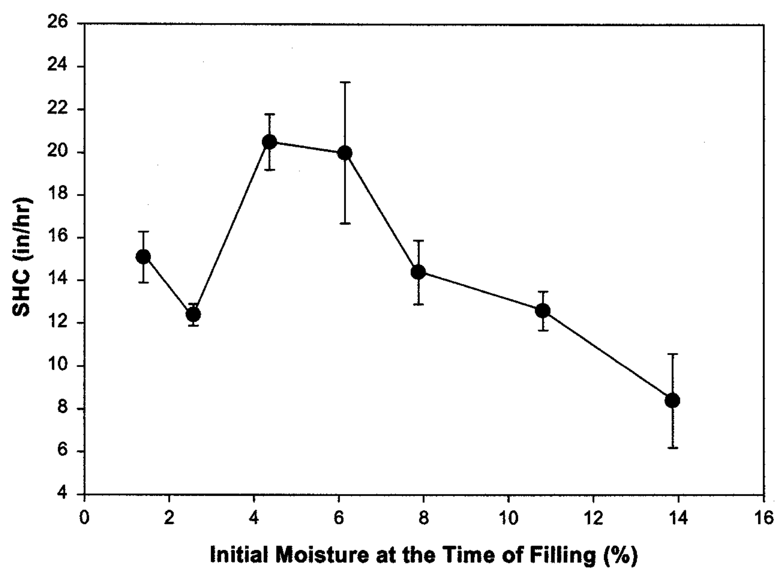


Figure 3. Relationship of initial green mix moisture (at column loading) on final SHC, Lab B. Sample provided by, Hall Irwin Company, Brighton, Colorado.

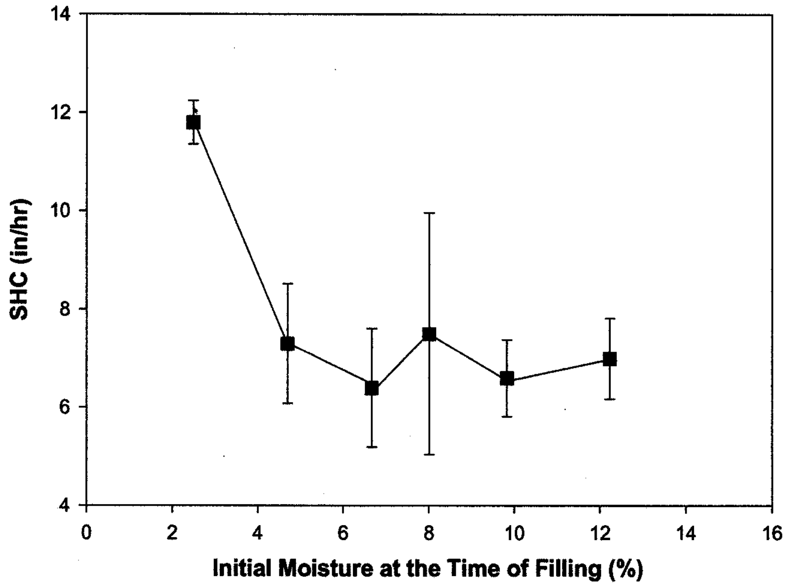


Figure 4. Relationship of initial green mix moisture (at column loading) on final SHC, Lab C. Sample provided by, Golf Agronomics, Sarasota, Florida

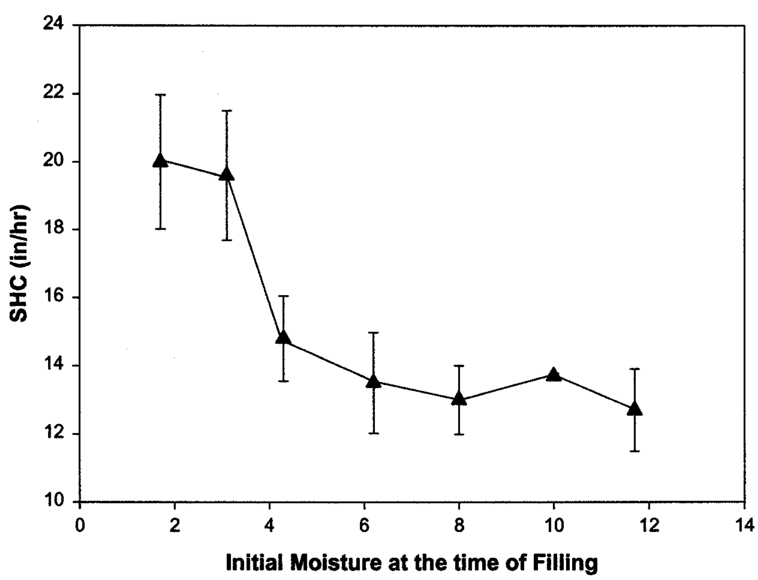


Figure 5. Relationship of initial green mix moisture (at column loading) on final SHC, Lab D. Sample provided by, TXI Industries, Austin, Texas.

C found an initial increase in K_{sat}, followed by a steep decline in values with increasing antecedent moisture. Non-cap and bulk density values were near constant across the range of antecedent moisture tested, whereas lab D found a initial decline followed by a near constant value. For both labs cap . For the Golf Agronomics material K_{sat} values for lab E first increase and then decreased. Again cap, non-cap and bulk density values were nearly constant across the range of moisture values tested. Lab F found results consistent with those of lab C.

Graphically the effect of antecedent moisture on K_{sat} is depicted in Figures 2 - 5 for four testing labs. Error bars listed for each data point reflect one standard deviation from the mean value reported. For lab A and the Hall Irwin material (Figure 2) K_{sat} declines from 1.7 to 9.3% antecedent moisture and then plateau's. The same material when submitted to Lab B (Figure 3), K_{sat} initially declines and then increases at 2.5 to 4.8% antecedent moisture and then again declines to 14% moisture.

Results for lab C (Figure 4) indicate an initial steep decrease in K_{sat} values followed by a plateau with increasing antecedent moisture. Note the large error bars for three of the data points for the Lab C plot. Lab D results indicate a continual decline in K_{sat} from 1.8% moisture to 6.4% moisture. There was no statistical differences in K_{sat} for antecedent moisture exceeding 5% for Lab C or lab D, and 9.3% for Lab A.

In summary for the three materials tested and five testing labs there is a general plateau in K_{sat} values for the antecedent moisture range of 6 to 10%, with a decline in higher values. Initial changes in K_{sat} as a function of moisture varies by labs and green mix. However, there appears to be consistency within laboratories (no comparisons can be made between labs due to differing samples) for the materials evaluated. Most significant were the results for cap, non-cap and bulk density which suggest that for antecedent moisture values above 2% these values are nearly constant, independent of lab or material (absolute values differ across labs). Most note worthy are that the changes in K_{sat} values with antecedent moisture have no relationship with cap, non-cap values or bulk density. Thus changes in K_{sat} values as a function of moisture are only associated with distribution of macro pores in the non-cap fraction. Using the current K_{sat} method, low antecedent moisture leads to a greater proportion of non-cap fraction macro-pores, whereas high moisture leads to a decrease in macro pores in the non-cap fraction which impedes water flow and results in low K_{sat}. The physics of macro pore distribution shifts as a function of moisture are not understood within the current K_{sat} method.

In the coming month, two more green mix materials will be prepared and sent to four more testing labs, which include: STRI, Brookside Labs, Rutgers University, Thomas Turf and Links Analytical.

Reference K_{sat} Columns

Initially variability in K_{sat} values was attributed to variation in percolation tables utilized int the for step *6* of ASTM F1815-97. It was postulated that a standard reference column (of known and constant K_{sat} value) would assist in documenting lab variability and could be used to calibrate the various percolation tables utilized amongst the USGA testing laboratories. Initially these columns were to be developed using packed glass bead columns. However experimentation has shown the glass bead packing structure was unstable which resulted in inconsistent K_{sat} values.

An alternative design which utilizes standard cylinders (50.0 mm ID X 75.0 mm height) constructed from copper tubing have been developed. This design utilizes a machined metal plate placed within the cylinder which contains micro bore holes ranging in size from 0.5 - 1.0 mm diameter. The number and diameter of the holes determines the rate of water flux through the column. Initial lab results (see Table 4) indicate the rate of water flow is highly consistent for each column over time but is dependent on water temperature. Generally the K_{sat} values are reproducible within 2%. These columns will be further tested in a second commercial laboratory and if results are successful the reference cylinders will be provided to all testing labs for evaluation and determination of individual lab percolation table bias for the K_{sat} measurements.

Table 4. K_{sat} values as a function of temperature for three reference columns[1].

Column	**Temperature**	**K_{sat}**	
	°C	Average (in/hr)	Standard Deviation
A	17	17.08	0.11
	18	18.69	0.10
	19	19.05	0.21
B	17	21.84	0.63
	18	23.65	1.60
	19	25.52	0.04
C	17	51.62	0.90
	18	53.77	0.36
	19	59.27	0.32

[1] Data provided by Diane: Ingvalson, Dakota Peat, East Grand Forks ND.

On Going Research

Research is underway on evaluating cylinder loading technique (Step *1* of ASTM F 1815-97). Cylinder loading techniques as documented on video of lab site assessments will be compared in a replicated study and assessed with regard to initial 30 cm moisture tension content. Focus will be on which technique provides the most consistency and an assessment of bias. In addition two tension table designs (comparable to those used by labs in the USA) are being evaluated for bias and precision.

Work is on going into the development of moisture model for antecedent moisture for sand. It is proposed to avoid the effect of antecedent moisture on K_{sat} values, to equilibrate root zone samples to a constant moisture using a predictive model based on sand and organic matter constituents prior to compaction. Initial results based archived sample data of ETL, Hummel and Company and Tifton Soil Testing indicate that organic matter, fine sand and very fine sand are predictive variables of water retention. Coefficients and model predictive variables are very similar to those reported by work in Germany.